Advanced Concepts Group

# News & Views

JUNE 2003

VOLUME 5, ISSUE 4

## Boldness, Resolution, Patience and Humility

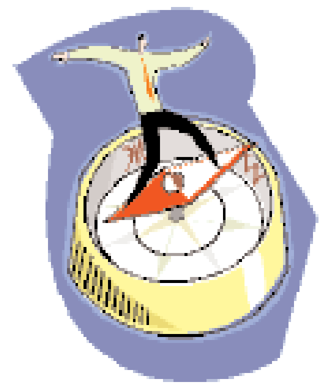
CURTIS JOHNSON
CJOHNSO@SANDIA.GOV

In the early years of World War II, the British Empire faced the first paratrooper attacks, engaged in the first large-scale tank warfare, lost millions of tons of shipping to new submarine and mine technologies and tactics, and endured nightly bombings of its homeland. Magnetic mines, incendiary bombs, time-delayed bombs, dive-bombing, and ship-launched planes were all new or nearly so. The "wizard war" of radar and radar-jamming pitted new technologies and new tactics against each other in nightly trials (and errors). With London in flames and England fearing imminent invasion, Winston Churchill told his people, "I have nothing to offer but blood, toil, tears and sweat."

Great Britain had no choice but to face its threats by trial and error. And the dire situation created tolerance for error in parliament and among the British people even though the costs of error were both high and immediate. The situation also forced difficult choices. It was not a time for sweeping doctrine or long-range strategy. Protecting everything was impossible. With so many immediate needs, protecting against threats not yet realized was out of the question. Boldness, resolution, patience and humility were needed (and found) in large measure.

Allies, enemies, threats and safeguards have been remarkably clear and stable since the end of World War II, a period that encompasses the entire history of the NSA, CIA, and DOE. The Cold War was, by design, a standoff, and as such, it was a conservative period with more stasis than change. The modern U.S. national security community has therefore never dealt with the level of uncertainty Great Britain faced in 1940 or what we face today. And the government agencies and agency heads we have today are a product of the Cold War. Those that are bold and resolute display little patience and humility. Those with the latter qualities are unwilling to take chances or face criticism.

Nonetheless, the British World War II spirit of experimentation and tolerance for error is much needed in homeland security in the U.S. today. The threats are once again new or unknown, the protections and countermeasures unproven. It is not at all clear what targets our enemies will choose or what means they will employ.



Compounding our challenge are the contrasts with Great Britain's dire straits. While styled as a "war," the anti-terrorism campaign does not appear so dire, so urgent, or so consuming as the threat of Hitler's Germany. Government agencies have pursued change ponderously. Congress and countless panels, reviews, and newspaper columnists have felt free to set unrealistic

### Inside this issue

> "Critics must insist not that we become safer than we were on 9/11, but that we become smarter. We must face the fact that we are unable to anticipate all, or perhaps even most, of the new threats."

expectations and throw rocks from the sidelines—sensationalizing threats, spreading fear, and educating the enemy all the while.

It is not so easy in 2003 as it was in 1940 to unite the government and the people, take our chances, and face our setbacks, but it is still necessary if we are to succeed in the war on terror. Leaders must be less paternal and simplistic and more realistic about the "blood, toil, tears and sweat" that may be ahead. Critics must insist not that we become safer than we were on 9/11, but that we become smarter. We must face the fact that we are unable to anticipate all, or perhaps even most, of the new threats. We must experiment in homeland defense and national security (even though lives are at stake) before committing years and billions (and the reputation of the administration) to their success. ■

# Wicked Problems Part B: The Battle

*John Whitley*
*jbwhitl@sandia.gov*

*Tom Karas*
*thkaras@sandia.gov*

In Part A of this series, we reviewed the paper by Rittel and Webber that defines the class of "wicked problems." The authors observe that the application of "scientific" principles such as efficiency and systems analysis have failed to improve the planning process, but offer little guidance for doing better. They believe that complex societal problems cannot be "reduced" as can a physics or engineering task. Breaking such problems down into separate pieces and trying to deal with them individually ignores essential interdependencies.

Rittel and Webber contrast the idealized planning process with reality:

1. Searching out goals…is an extraordinarily obstinate task;
2. Identifying problems… cannot be done independent of solutions;
3. Forecasting uncontrollable contextual changes…is impossible in a chaotic world;
4. Inventing alternative strategies, tactics, and time-sequenced actions...is never a complete, or optimal set;
5. Simulating alternative and plausible action sets and their consequences...is very difficult;
6. Evaluating alternatively forecasted outcomes...is done by whose criteria?
7. Statistically monitoring the conditions of the germane publics and systems that are judged to be germane...is doable if we can actually agree what to measure and how to measure it; and
8. Feeding back information to simulation and decision channels so that errors can be corrected—all in a simultaneously functioning governing process...must work within the relevant bureaucratic and political systems.

In general, we do not seem to take very effective approaches toward wicked problems. See if you don't recognize at least some of the following ineffective approaches (*www.cognexus.org/id29.htm*):

1. Never-ending studies (leading to analysis paralyses);
2. Taming the untamable (let's set some artificial system boundaries and plow ahead);
3. Lock down the problem definition (let's just agree to quit analyzing and solve something);

- **Fighting terrorism**
- **Whether to route the new highway through the city or around it**
- **A national healthcare system for the U.S.**
- **Sprawl and sustainable development**
- **What to do when oil resources run out**
- **The U.S. Social Security System**
- **World hunger**
- **Global warming**

***Figure 1.*** *Examples of wicked problems*

4. Declare the problem solved (this often makes people happy!);
5. Specify objective parameters to measure success (we love to do this for education; let's just define some metrics and assume the problem will improve if we work on those);
6. Cast the problem as "just like" another that has been solved, ignoring differences (maybe no one will notice);
7. Give up. Just follow orders and try not to get in trouble (we'd never do that!); or
8. Pretend there are only a few solutions and focus on selecting among those (similar to #3; let's just get to work on something and it'll all work out somehow).

So, given that many of our problems are wicked problems, and that we are often not satisfied with our solutions or even our approach to a solution, then what can we do? Can systems thinking help? What about complexity theory? Have recent advances in these areas opened up new possibilities for dealing with wicked problems?

### Systems Thinking for "Wicked" Systems: Gharajedaghi

There are a host of systems books and approaches, most of which are quite adequate for sorting out an approach to a complex problem once the system boundaries have been defined and the "requirements" stated. For problems that resist clearly stated requirements, a more helpful approach is given by Jamshid Gharajedaghi in his book, *Systems Thinking, Managing Chaos and Complexity* (1999, Butterworth-Heinemann). Gharajedaghi approaches the human organization as a holistic, multiminded, purposeful system that does not display the conflict-resolving paternalistic figure common in traditional organizations. These systems generate high levels of conflict and their parts often disagree on both ends and means. He also stresses that individual decision-making is not a process based only on rational thought, but is also influenced by emotion and culture.

Wicked problems fall into the class of nasty problems that he calls a "Mess"—a system of problems. It is an emergent phenomenon that displays properties quite different from the properties of its constituent parts. Emergent properties like love, happiness, and terrorism are the properties of the whole, not the parts; if you take them apart you lose their essential properties. That is why one cannot reduce the problem and analyze them separately.

The biggest challenge in applying Gharajedaghi's philosophy to wicked problems is that he insists that the problem (a) must be defined *free of solutions*, (b) should not be defined as a lack of resources, and (c) should not be defined in reference to the "norm." However, he does recognize that "success changes the game"—that once a solution is implemented, the context changes and the solution may no longer be valid. His process is iterative. You start with a clean sheet approach, evaluating the system's function, structure, process, and environment. You then take the problem statement and create an idealized design, where an idealized design is the most exciting version of the achievable future that the designers are capable of producing. This idealized design is then pursued through a process of successive approximation, working to remove constraints that block the implementation.

Gharajedaghi's approach is all about recognizing and managing the chaos. He strives to create cultures that achieve high levels of integration at the same time they allow high levels of differentiation. Systems often fail to manage these two characteristics successfully and move into an unstable, oscillating mode of operation. Successful organizations that manage both integration and differentiation can achieve emergent behaviors that surpass the sum of the components. In sum, it appears that the Gharajedaghi iterative approach can help resolve wicked problems if one works to include all stakeholders in the problem/solution discussion cycle and recognizes the interdependencies of

### ACG Weekly Brainstorm Sessions!!

Please join us for our weekly brainstorm sessions every Friday, 9:00-11:00 a.m! Please check out the "upcoming events" on our web page for a list of scheduled topics. If you have a topic to suggest, please contact Simon Goldfine at srgoldf@sandia.gov or 845-0917.

problem definition to solution. His approach is insightful, but not very definitive and certainly lacking in specifics.

### The Science of Complexity

In the late 1970's, the development of the formal mathematics of chaos started a large effort to understand complex, interacting systems with emergent properties. Multi-disciplinary teams have formed to capture diversity in such systems and to understand the dynamics of how order evolves from chaos. Network theory provides a structural framework for interconnecting multiple systems to account for feedback loops and non-linear, co-evolutionary behaviors. In complexity science, the self-organizing behaviors (which lead to "perpetual novelty") are captured through mechanisms of learning and adaptation. Agent based modeling, one tool of complexity science often used in conjunction with network theory, attempts to model human behavior in group settings. All of this could be very relevant to the resolution of wicked problems as the field continues to mature.

### Tackling Wicked Problems

Wicked problems appear to require effective socio-political processes in addition to effective systems analysis. There are some tools and techniques for improving socio-political processes: e.g., conflict resolution, consensus building, various gaming techniques, and pervasive communication technologies are enabling new techniques such as web based meetings and electronic voting. The biggest challenge in dealing with wicked problems seems to be to enable the socio-political process to assure that the interest of the public is paramount in framing the problem. Since wicked problems have no definitive formulation, there is no end to the casual chains that link all the interacting open systems; but, at some point, the socio-political discussion has to be bounded to allow progress. The key is to create a process that involves all interested stakeholders in moving toward a consensus solution.

**The CogNexus Institute states the issue this way:**

"Problem wickedness demands collective intelligence, or more precisely, tools and methods which create shared understanding and shared commitment. There will be volumes of facts, data, studies and reports about a wicked problem, but the shared commitment needed to create durable solution will not live in information or knowledge. Understanding a wicked problem is about collectively making sense of the situation and coming to shared understanding about who wants what." (www.cognexus.org/id42.htm)

Technical tools might play critical roles in resolving wicked problems. For example, system models can help identify complex interactions and more predictive models might help investigate the impact of decisions. Since at least some of the difficulty in dealing with wicked problems has to do with the inability to foresee the consequences of various solution options, there is some hope that advances in computing or more sophisticated gaming techniques could help. What is needed is a large enough system model to exhibit the subtle emergent behaviors that might be created by an option. Large agent based models of social behavior may lead to useful tools, but there is much work to be done. It is very difficult to sort out a wicked problem's interlocking issues and constraints, especially since they change over time and are embedded in a dynamic social context. There is no "natural" level of analysis for a wicked problem, and it is difficult to see modeling and analysis tools overcoming this fundamental obstacle.

Before we end, we would like to propose one other characteristic for some wicked problems: **they may have costs and benefits that are not realized in the stakeholder's lifetime**. A good example of this is the issue of climate change. How should we analyze a problem whose potential solutions may impose costs on the current generation without giving it much benefit, but whose neglect might impose huge costs on following generations? We are depending on long range modeling ability to study this problem, but the results are not clear. Definitely another characteristic of a wicked problem.

### Conclusion

Unfortunately, there is no good conclusion. Wicked problems are the really hard problems, and all our computing and thinking will never succeed in formalizing the solution. Gharajedaghi at least recognizes the scope of the problem. Many others are working on the social interaction part, because when it is all said, wicked problems are about social complexity. Solutions that satisfy one may be abhorrent to another. Problem solution for one is problem generation for another. In wicked problems, the intersection of social complexity (whether in the workplace or public arena), with technical complexity usually leads to blame and little real progress.

Although wicked problems cannot, strictly speaking, be "solved," perhaps there are at least some approaches that might help us deal with them a little better, since deal with them we must:

- It is most critical to identify wicked problems for what they are. Don't pretend they are tame.
- Try to tame the problem if possible.
- Be conscious of the arbitrary boundaries that are being drawn in system space
- Explore all technology options to address the problem.
- Try to increase the amount of agreed factual parts of the problem; can you decrease uncertainties, increase knowledge and/or improve tools for forecasting consequences?
- Be adaptive and iterative.
- Since you cannot experiment with large-scale solutions and can't take back effects of what's been done, see if you can break the problem up into steps where you can experiment. Can you pilot and scale up?
- The end state is more of a meta-state; where are you in the hierarchy of the solution/problem space; realize that although you have to measure something, it just won't be the final solution.
- Understand the nature of problems in terms of the process by which they are addressed: context, players, meta-analysis.
- Investigate all possible ways to build consensus.
- Try to amend the process to allow consensus to be built.
- Think about who is the "you" in defining a problem; what is your role; how can you hope to contribute to and shape the solution process
- If you can't change the process, then at least figure out how to be a more effective player in it.
- Be sensitive to ways in which solutions are presented to affected parties. ■

## The Observable Human

Rick Craft
rlcraft@sandia.gov

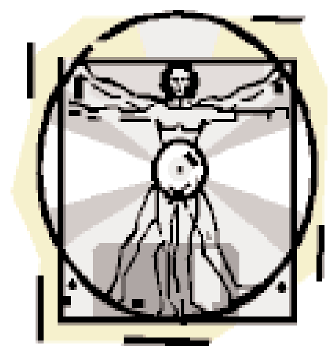
Much of what we do in everyday life depends on our ability to observe other people. When we talk with others, we continuously watch them to determine how well the interactions are going—"Do I have their attention?" "Are they understanding what I am saying?" or "Are they comfortable or uncomfortable with how this conversation is going?"—and we use the cues that we receive to modulate our own behavior. Professionals, like doctors or policemen, whose jobs require them to specialize in observation of people will use these skills to assess an individual's state of well being or character. Psychologists and sociologists observe individuals and groups in order to learn about their mental state, their beliefs, etc. Educators use observation to determine what their students have comprehended.

Assuming current technology trajectories, within

> "This can be challenging, as human experts often do not know themselves exactly what it is that they are sensing in these processes."

the next decade and a half (give or take a few years), information technology will have advanced to the point that developers of engineered systems will regularly face the question of how to enable intelligent machines to "understand" the humans that populate their environments. When this occurs, one of the key needs will be for sensory mechanisms that enable these machines to observe the humans with whom they interact. Developing these mechanisms will be an important task for the engineering community during the period leading up to this time. While some people might correctly argue that we already have mechanisms for observing many different things about people, a fatal flaw associated with many of these mechanisms is that they can only be used in certain limited operational settings. For example, a person's stress level, as indicated by the amount of cortisol in their bloodstream, can only be determined by drawing blood and analyzing it with bench-top equipment in a medical lab. Because mechanisms like these are too large, too fragile, too expensive, or must be collocated with operators possessing specific expertise, they require that a person be brought to them in order for an observation to be made. What will be needed in this future world of human-machine collectives will be devices that allow the sensing to be brought to the human, irrespective of where a person may be operating or what he may be doing. Like Mutual of Omaha's *Wild Kingdom*, we will want to be able to observe people in their natural habitats.

So what will it take to deliver these devices? First, there are a number of systems questions that need to be answered. For example, while the number of things that might be observed about individuals and groups is enormous, it is not clear which of these things are most important to measure and why. Similarly, out of all of the mechanisms that exist for observing various things about people, it is not clear which are amenable to reengineering in ways that allow for "anywhere, anytime" observation to occur. In cases where certain observations are deemed to be high value but there seems to be no reasonable way to create a mechanism for ubiquitous collection of that information, it would be helpful if correlations that might be more easily collected could be identified. If these questions could be addressed, the device development community would be able to identify the "low-hanging fruit" in this problem space (i.e., those things that would be both valuable and easy to observe) and these capabilities could be brought to the field quickly. For those organizations that fund basic and applied research in devices, identifying those capabilities that are deemed valuable but are moderately difficult or difficult to implement would help them establish rationale research agendas aimed at addressing these needs.



Second, basic research into observation of humans may need to be pursued. In many cases of observation of humans, the only collection mechanisms available for making the observations are other humans. For instance, a significant part of the value of experienced nurses in intensive care units is their ability to intuitively assess a patient's state of well-being. Very often, they can tell that a patient is not doing well even before the monitors connected to the patient indicate that something is wrong. If computers are to take on these kinds of roles, then research into what exactly the humans are observing and how this can be captured technically needs to be pursued. This can be challenging, as human experts often do not know themselves exactly what it is that they are sensing in these processes.

Third, the actual engineering work involved in developing these devices will need to be done. Beyond the normal design and fabrication activities, this task necessarily involves field trials to characterize the devices and to evaluate their ability to perform as intended in a broad range of operational settings. This will very likely require collaboration between engineers and experts from a broad range of human-focused disciplines.

Having said all of this, it is important to note that much is known already about sensors and about humans but that it has not been organized and catalogued in a way that lends itself to the purposes described here. While the knowledge is scattered across a wide range of disciplines in ways that make it difficult to analyze global needs and to identify opportunities, the upside of this is that a program focused on delivering this new generation of devices already has a lot of science on which to build and should be able to demonstrate a number of significant near-term "wins".

So, is there a role for Sandia to play in all of this? Clearly, the answer is "yes." With its strong background in microsystems and related technologies and with facilities like MESA, the Labs could become one of the chief sources of device designs for this new generation of sensors. With its systems orientation, Sandia could also spearhead the analytical work required to assess the relative importance of different observables and the feasibility of recasting different observation mechanisms as cheap, rugged, widely deployable devices.

Could Sandia do this unilaterally? Absolutely not. The breadth of expertise required for a program of this sort exceeds our reach. Many of the disciplines that would be required to conduct the systems work or to evaluate the efficacy of device designs are not represented on Sandia's staff. Also, the magnitude of the effort suggests that partnering with a broad-based coalition of external expertise may be essential in order for this effort to be successful.

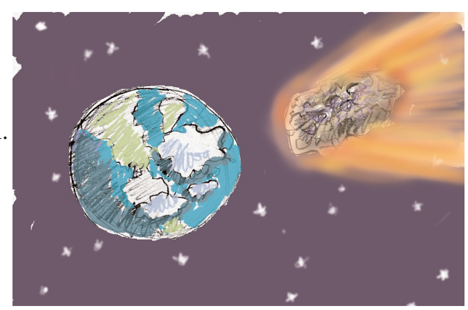
One strategy that Sandia could pursue in order to address the system engineering issues is the establishment of a national-level "Observable Human Project." In this effort that would engage a broad coalition of experts drawn from academia, government, and the private sector, an on-line repository would be created that could be used to catalog everything that could be observed about a human. This repository would also be used to identify the relevance of each such observable to various applications, to capture the relative importance of each of these applications, to enumerate all of the mechanisms that can be used to make a given kind of observation, and to record an assessment of the relative difficulty of reengineering each of these mechanisms in ways that support ubiquitous deployment. Once created, teams of experts from various fields would populate this catalog with the observables that are relevant to their field. These and other experts would be used to address questions related to the value of these observables and the mechanisms available for their capture. Sandians and others with expertise in microsensing and related technologies would be used to assess the difficulty of casting these mechanisms in appropriate form.

When coupled with the power to make sense out of what is perceived, the ability of machines to observe in detail humans operating in virtually any setting will transform the world. It is not a question of whether this future will come, but when and through whom. ■

# A Good Planet is Hard to Find

Peter Merkle
pbmerkl@sandia.gov

A self-sustaining human colony on Mars, with an engineered ecology for life support, would constitute an insurance policy against a global catastrophe on Earth. The geologic record provides evidence of regular asteroid impacts of a severity sufficient to drastically impair or reverse the progress of technological civilization, if not destroy all higher forms of life. I grant you, these events are rare, perhaps occurring at a rate of 1 per 65 million years, but they do occur. We don't know the chances of other



> "Is it legitimate to speculate that we might impair our civilization significantly and comparably to a killer asteroid strike through human means such as a strategic nuclear exchange or advanced biological warfare over that time?"

extinction-class events, but scary phenomena are documented in the geologic record. A magnetic field lapse preceding polarity reversal would blast the Earth's surface with dangerous radiation. Pandemic diseases of humans or staple crops are not unprecedented. An accidental full nuclear exchange would poison the biosphere with unforeseen consequences. Given all the potential catastrophes and incomplete knowledge, how much would a rational insurer require us to pay each year for a policy insuring the continued economic and cultural activities of the entire planet? I submit that this risk premium is a guide to what should be invested yearly in a Mars colony and other global risk mitigation technologies, whatever those might be.

Let's examine a worst-case scenario, a global extinction asteroid. In 2000, global GDP estimates are around $29 trillion in constant 1990 dollars. For purposes of conservative analysis, assume this does not grow. Let's assume that we have a 25-year time horizon, in that we expect this GDP delivered every year, and the discount rate is 3%. The net present value of this revenue stream is about $500 trillion. Why use 25 years? It is legitimate to speculate that we might impair our civilization significantly and comparably to a killer asteroid strike through human means such as a strategic nuclear exchange or advanced biological warfare over that time?


What is the likelihood of a killer asteroid impact in any year? The last one we know of was about 65 million years ago, which is roughly the periodicity of several such events in the geological record. One might confidently argue that we are about due for one! It is theorized that periodic disturbances of the Oort cloud of cometary bodies surrounding our solar system are responsible for this observed periodicity, perhaps caused by the long orbit of a dark companion body to the Sun. Whatever the cause, let's guess that the risk of an extinction event in any year is 1 in 65 million. Now maybe I'm naïve, but multiplying net present value of global GDP by the yearly extinction likelihood tells me that buying an insurance policy for $7.7 billion a year is a good idea! Note this analysis places no value on the irreplaceable natural Earth resources, lost use, and pain and suffering, and includes no profit margin for the insurer. The actuarial value of all human life is accounted for in the proxy figure of global GDP.

By this very crude analysis, it is a rational strategy to invest around $8 billion dollars a year in the establishment of a self-sustaining colony on Mars, or even better, an interstellar exploration and colonization program. (Even a Mars colony would not eliminate all extinction threats, as risks from a gamma ray burst in our local star cluster neighborhood or a solar nova still remain.) The 2004 NASA budget request is $15.5 billion. So, there is evidence we are comfortable as a species investing the scale of resources in space technology that could one day lead to another home and a backup plan for Earth. Maybe it is just a question of priorities: with a global military budget near $800 billion, why not invest 1% in a rational global risk mitigation strategy? ■

# National Security, the Homeland, and Complexity

Nancy Hayden
nkhayde@sandia.gov

During times of peace, national security has always been difficult to measure explicitly, yet easy enough to determine implicitly as a sense of public well-being. You know it when you have it, and when you don't. We knew we had lost our sense of it on September 11, 2001. On that day, for the first time in over fifty years, national security came to mean homeland security, and then some.

September 11 unequivocally clarified the reality of a deadly, long-term campaign against the U.S. as a result of the modernization and globalization epitomized by our society in the eyes of Islamic fundamentalists. We have since been struggling to understand the nature of the ever changing threat, our apparently limitless vulnerability to that threat, and the dynamic, non-linear feedback between our responses to the threat and its evolution.

Our society functions as a complex, interconnected "system of systems" of diverse natures—biological, man-made and societal—that evolve over a wide range of timeframes to perform multiple and different functions depending on the environmental conditions. Homeland security demands an analysis framework that is valid within each of these diverse systems, yet can also be applied across the interconnected whole. To complicate matters, homeland security requires that we extend our gaze beyond our own borders to examine the nature of the threat—itself a complex adaptive system operative across different political, cultural, socio-economic, religious and geographic boundaries, and consider strategies for problem prevention in addition to crisis response.

Over the last two decades, during which time the call for Jihad against the West has been developing a larger and larger constituency among Islam fundamentalists, the science of complexity has also been developing and has reached a level of maturity that can begin to provide a theoretical and practical basis for tackling the difficult problem of regaining and maintaining our sense of security.

The concepts of chaos and complexity reach far back in history. However, it was not until the late 1970's that a formal framework began to evolve that sparked systematic research into complex systems. In 1975, Li and York first formulated chaos as a mathematical time evolution problem in which there is sensitive dependence on initial conditions. Several years later, Ilya Prigogine, the 1977 Nobel Prize winner in chemistry, used dissipative systems to show that more complex structures can evolve from simpler ones—order coming out of disordered chaos. The science of complexity that has evolved since seeks to discover and understand the underlying universal laws which guide the emergence of regularity from randomness, the evolution of the structural form of such systems, and the dynamics that operate on them. As stated by Murray Gell-Mann in his book, *The Quark and the Jaguar*, "one of the greatest challenges of contemporary science is to trace the mix of simplicity and complexity, regularity and randomness, order and disorder up the ladder from elementary particle physics and cosmology to the realm of complex adaptive systems."

Perpetual novelty is a hallmark of complex systems, and it is this characteristic that makes understanding complex systems vital to our national security interests, and at the same time makes them uniquely difficult to study scientifically. Advancements in computing power in the past twenty years have opened up a venue for inquiry through simulations, which have produced new and surprising insights into the behavior of complex adaptive systems, and have led to new hypotheses and mathematical formulations for theoretical grounding. The body of knowledge that has been generated is "just in time" for addressing homeland security.

The beauty and power of analytic tools derived from complexity science is that they have been shown to have properties and dynamics that transcend expertise domains and system types—network analysis in particular. Network analysis examines how the structural form of complex systems evolve and grow over time, and where key levers are located, what dynamics are operative on the structure—resulting in synchronization and emergent properties—and where phase transitions can occur. Agent based modeling, which has become a mainstay of complex systems analysis, at the node level of networks, allows for self-organization and evolution, and can incorporate effects of

**"The science of complexity that has evolved since seeks to discover and understand the underlying universal laws which guide the emergence of regularity from random-ness, the evolution of the structural form of such systems, and the dynamics that operate on them."**

# About the ACG *News & Views*

**The ACG *News & Views* is published monthly by the Vice President and Principal Scientist, Division 16000, to share new ideas, concepts and opinions. We welcome interesting dialogue about the issues/views presented in this publication and encourage our readers to contact us or submit articles explaining their views.**

**For more information about the newsletter, please contact Alicia Cloer at aacloer@sandia.gov.**

**For information about any of the subjects discussed in the newsletter, contact the author(s) directly.**

competition, learning, natural selection, mimicry, etc.

There are still many open research questions in studying complex systems. Some of the more pragmatic are: how does one connect across network domains; how does one build learning modules into agents; how does one detect transition points (whether they are evolutionary leaps, phase transitions, or lever points, etc). That said, there is much to be gained for homeland security by using the science in its present state.

However, there remains much confusion (and disagreement) among policy officials, analysts, modelers and researchers (not to mention decision makers themselves) about the appropriate application of the tools and methods, what questions can be addressed with what degree of rigor, and what kind of data sets are required. Murray Gell-Mann cautions that computer simulations should be treated as "prostheses for the imagination and not attribute to them more validity than they are likely to possess." As often happens in the sea of such confusion, there is a danger of spending much to get nothing, and in the end, spoiling the opportunity for significant scientific and social contributions for real national/homeland security issues. In using these tools and models for homeland security, the following questions need to be considered:

- What is the appropriate level of detail and fidelity to the real process or phenomenon required for a model to answer a particular analysis question?
- How will one ensure that the mathematical (phenomenological) formulation in the model that is grounded in sound domain expertise and theory?
- Does the model allow for a mathematically rigorous sensitivity and statistical analysis of the results for meaningful interpretation?
- Are the data visualization techniques adequate to find and communicate all critical parameters of interest?

Los Alamos has engaged in theoretical research into complex systems behaviors in its Center for Nonlinear Studies for over 23 years, the Santa Fe Institute is celebrating twenty years of basic research in this field, and the expertise resident at Sandia for modeling complex systems, like that in some parts of the community of practice, has recently emerged in distinct hubs around specific problems.

Since 9/11, however, there has been a proliferation of workshops, seminars, and independent studies exploring complexity science as a means for homeland security analysis, and we have begun to see these different parts of the community (pragmatic problem solvers and theoretical researchers) come together. We encourage more of the same to take advantage of new advances in the field, to guide the appropriate application of the tools of complexity science, and to provide direction for research agendas…to create emergent phenomenon within the field of study itself. ■

Happy Independence Day!